



Ozone Disinfection

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Introduction

Human exposure to wastewater discharged into the environment has increased within the past 15 to 20 years with the rise in population and the greater demand for water resources for recreation and other purposes. The organisms of concern in domestic wastewater include enteric bacteria, viruses, and protozoan cysts. Some common microorganisms found in domestic wastewater and the diseases associated with them are presented in Table 1.

Table 1: Infectious Agents Potentially Present in Untreated Domestic Wastewater

Organism	Disease Caused
Bacteria	
<i>Escherichia coli</i> (enterotoxigenic)	Gastroenteritis
<i>Leptospira</i> (spp.)	Leptospirosis
<i>Salmonella typhi</i>	Typhoid fever
<i>Salmonella</i> (~2,100 serotypes)	Salmonellosis
<i>Shigella</i> (4 spp.)	Shigellosis (bacillary dysentery)
<i>Vibrio cholerae</i>	Cholera
Protozoa	
<i>Balantidium coli</i>	Balantidiasis
<i>Cryptosporidium parvum</i>	Cryptosporidiosis
<i>Entamoeba histolytica</i>	Amebiasis (amoebic dysentery)
<i>Giardia lamblia</i>	Giardiasis
Helminths	
<i>Ascaris lumbricoides</i>	Ascariasis
<i>T. solium</i>	Taeniasis
<i>Trichuris trichiura</i>	Trichuriasis
Viruses	
Enteroviruses (72 types, e.g., polio, echo, and coxsackie viruses)	Gastroenteritis, heart anomalies, meningitis
Hepatitis A virus	Infectious hepatitis
Norwalk agent	Gastroenteritis
Rotavirus	Gastroenteritis

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Disinfection is considered to be the primary mechanism for the inactivation/ destruction of pathogenic organisms to prevent the spread of waterborne diseases to downstream users and the environment.

It is important that wastewater be adequately treated prior to disinfection in order for any disinfectant to be effective.

There is no perfect disinfectant. However, there are certain characteristics to look

for when choosing a suitable disinfectant for a treatment facility:

- ability to penetrate and destroy infectious agents under normal operating conditions;
- lack of characteristics that could be hazardous to people and the environment before or during disinfection;
- safe and easy handling, storage, and shipping;
- absence of toxic residuals and mutagenic or carcinogenic compounds after disinfection; and
- affordable capital and operation and maintenance (O&M) costs.

Disinfection Alternatives

The three most common methods of disinfection in the U.S. are chlorination, ozonation, and ultraviolet (UV) disinfection. Chlorine, the most widely used disinfectant for municipal wastewater, destroys target organisms by oxidation of cellular material. It may be applied as chlorine gas, hypochlorite solutions, and other chlorine compounds in solid or liquid form.

Like chlorine, ozone is a strong oxidizing agent. It is an unstable gas that is generated by an electrical discharge through dry air or pure oxygen. UV radiation, generated by an electrical discharge through mercury vapor, penetrates the genetic material of microorganisms and retards their ability to reproduce.

All three disinfection methods described above can effectively meet the discharge permit requirements for treated wastewater. However, the advantages and disadvantages of each must be weighed when selecting a method of disinfection. The advantages and disadvantages of ozone disinfection are discussed below.

Advantages

- Ozone is more effective than chlorine in destroying viruses and bacteria.
- The ozonation process utilizes a short contact time (approximately 10 to 30 minutes).
- There are no harmful residuals that need to be removed after ozonation because ozone decomposes rapidly.

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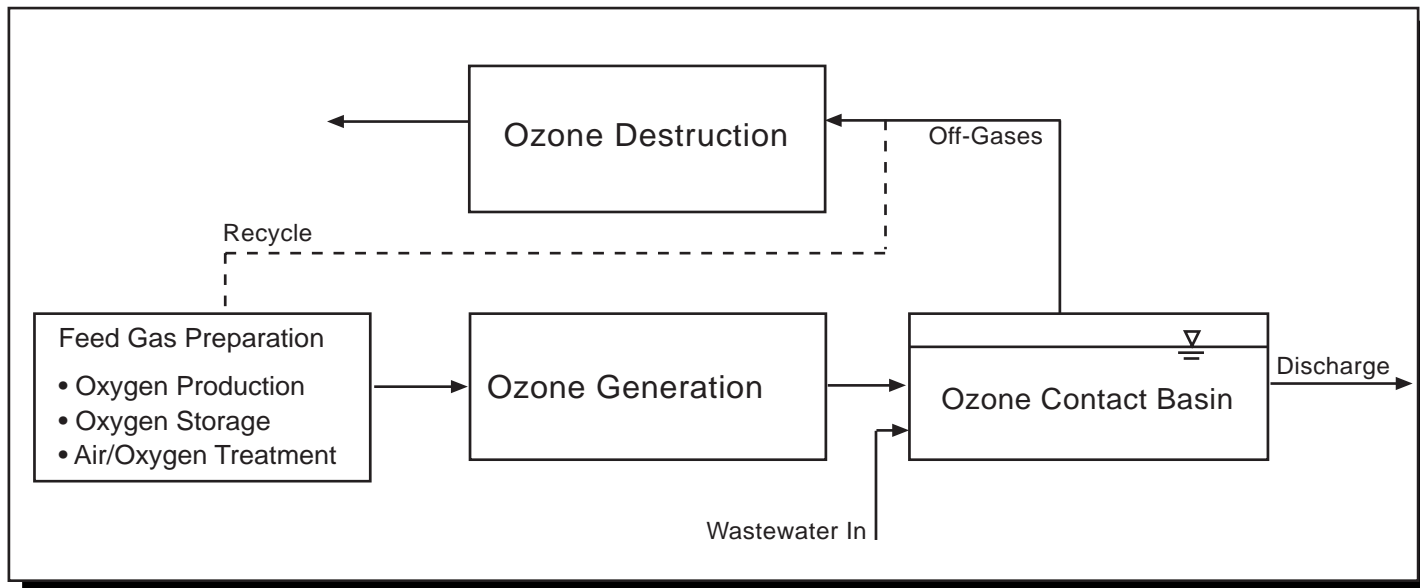


Figure 1: Ozone Disinfection Process Diagram

Adapted from U.S. Environmental Protection Agency (1986)

- After ozonation, there is no regrowth of microorganisms, except for those protected by the particulates in the wastewater stream.
- Ozone is generated onsite, and thus, there are fewer safety problems associated with shipping and handling.
- Ozonation elevates the dissolved oxygen (DO) concentration of the effluent. The increase in DO can eliminate the need for reaeration and also raise the level of DO in the receiving stream.

Disadvantages

- Low dosages may not effectively inactivate some viruses, spores, and cysts.
- Ozonation is a more complex technology than is chlorine or UV disinfection, requiring complicated equipment and efficient contacting systems.
- Ozone is very reactive and corrosive, thus requiring corrosion-resistant material, such as stainless steel.
- Ozonation is not economical for wastewater with high levels of suspended solids (SS), biochemical oxygen demand (BOD), chemical oxygen demand, or total organic carbon.
- Ozone is extremely irritating and possibly toxic, so off-gases from the contactor must be destroyed to prevent worker exposure.
- The cost of treatment can be relatively high, being both capital- and power-intensive.
- There is no measurable residual to indicate the efficacy of ozone disinfection.

Process Description

Ozone is produced when oxygen (O_2) molecules are dissociated by an energy source into oxygen atoms and subsequently collide with an oxygen molecule to form an unstable gas, ozone (O_3), which is used to disinfect wastewater. Most wastewater treatment plants generate ozone by imposing a high voltage alternating current (6 to 20 kilovolts) across a dielectric

discharge gap that contains an oxygen-bearing gas. Ozone is generated onsite because it is unstable and decomposes to elemental oxygen in a short amount of time after generation.

Ozone is a very strong oxidant and virucide. The mechanisms of disinfection using ozone include:

- direct oxidation/destruction of the cell wall with leakage of cellular constituents outside of the cell,
- reactions with radical by-products of ozone decomposition,
- damage to the constituents of the nucleic acids (purines and pyrimidines), and
- breakage of carbon-nitrogen bonds leading to depolymerization.

When ozone decomposes in water, the free radicals hydrogen peroxy (HO_2) and hydroxyl (OH) that are formed have great oxidizing capacity and play an active role in the disinfection process. It is generally believed that the bacteria are destroyed because of protoplasmic oxidation resulting in cell wall disintegration (cell lysis).

The effectiveness of disinfection depends on the susceptibility of the target organisms, the contact time, and the concentration of the ozone.

See Figure 1 for a line diagram of the ozonation process. The components of an ozone disinfection system include feed-gas preparation, ozone generation, ozone contacting, and ozone destruction.

Air or pure oxygen is used as the feed gas source and is passed to the ozone generator at a set flow rate. The energy source for production is generated by electrical discharge in a gas that contains oxygen. Ozone generators are typically classified by:

- the control mechanism (either a voltage or frequency unit);
- the cooling mechanism (either water, air, or water plus oil);
- the physical arrangement of the dielectrics (either vertical or horizontal); and
- the name of the inventor.

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However, generators manufactured by different companies have unique characteristics but also have some common configurations.

The electrical discharge method is the most common energy source used to produce ozone. Extremely dry air or pure oxygen is exposed to a controlled, uniform high-voltage discharge at a high or low frequency. The dew point of the feed gas must be -60°C (-76°F) or lower. The gas stream generated from air will contain about 0.5 to 3% ozone by weight, whereas pure oxygen will form approximately two to four times that concentration.

After generation, ozone is fed into a down-flow contact chamber containing the wastewater to be disinfected. The main purpose of the contactor is to transfer ozone from the gas bubble into the bulk liquid while providing sufficient contact time for disinfection. The commonly used contactor types are diffused bubble (co-current and counter-current) positive pressure injection, negative pressure (Venturi), mechanically agitated, and packed tower. Because ozone is consumed quickly, it must be contacted uniformly in a near plug flow contactor.

The off-gases from the contact chamber must be treated to destroy any remaining ozone before release into the atmosphere. Therefore, it is essential to maintain an optimal ozone dosage for better efficiency. When pure oxygen is used as the feed gas, the off-gases from the contact chamber can be recycled to generate ozone or for reuse in the aeration tank. The ozone off-gases that are not used are sent to the ozone destruction unit or are recycled.

The key process control parameters are dose, mixing, and contact time. An ozone disinfection system strives for the maximum solubility of ozone in wastewater, as disinfection depends on the transfer of ozone to the wastewater. The amount of ozone that will dissolve in wastewater at a constant temperature is a function of the partial pressure of the gaseous ozone above the water or in the gas feed stream.

It is critical that all ozone disinfection systems be pilot tested and calibrated prior to installation to ensure that they will meet discharge permit requirements for their particular sites.

Application

Ozone disinfection is generally used at medium- to large-sized plants after at least secondary treatment. In addition to disinfection, another common use for ozone in wastewater treatment is odor control.

Belmont and Southport Wastewater Treatment Plants in Indianapolis, Indiana

In 1985, the city of Indianapolis, Indiana, operated two 125 million gallons per day (mgd) advanced wastewater treatment plants at Belmont and Southport using ozone disinfection. The rated capacity of the oxygen-fed ozone generators was 6,380 pounds per day, which was used to meet geometric mean weekly and monthly disinfection permit limits for fecal coliforms of 400 and 200 per 100 mL, respectively.

Disinfection was required at both Indianapolis treatment plants from April 1 through October 31. Equipment performance characteristics were evaluated during the 1985 disinfection season, and consequently, disinfection performance was optimized during the 1986 season. The capital cost of both ozone systems represented about 8% of the plants' total

construction cost. The ozone system O&M cost represented about 1.9% and 3.7% of the total plant O&M cost at the Belmont and Southport plants, respectively.

In 1989, a disciplined process monitoring and control program was initiated. Records indicated a significant effect on process performance due to changes in wastewater flow, contactor influent fecal coliform concentration, and ozone demand.

Previously, ozone demand information was unknown. Several studies were conducted to enable better control of the ozone disinfection process. These included the recent installation of a pilot-scale ozone contactor to allow the plant staff to measure ozone demand on a daily basis. Also, tracer tests were conducted to measure contactor short-circuiting potential. Results demonstrated a noticeable benefit of adding additional baffles. Results also indicated operating strategies that could maximize fecal coliform removal, such as reducing the number of contactors in service at low and moderate flow conditions.

Operation and Maintenance

Ozone generation uses a significant amount of electrical power. Thus, constant attention must be given to the system to ensure that power is optimized for controlled disinfection performance.

There must be no leaking connections in or surrounding the ozone generator. Therefore, leaks should be checked for routinely, since a very small leak can cause unacceptable ambient ozone concentrations. The ozone monitoring equipment must be tested and calibrated as recommended by the equipment manufacturer. The operator must on a regular basis monitor the appropriate subunits to ensure that they are not overheated.

Like oxygen, ozone has limited solubility and decomposes more rapidly in water than in air. This factor, along with ozone's reactivity, requires that the ozone contactor be well covered and that the ozone diffuses into the wastewater as effectively as possible.

Ozone in gaseous form is explosive once it reaches a concentration of 240 g/m^3 . Since most ozonation systems never exceed a gaseous ozone concentration of 50 to 200 g/m^3 , this is generally not a problem.

However, ozone in gaseous form will remain hazardous for a significant amount of time; thus, extreme caution is needed when operating the ozone gas systems. It is important that the ozone generator, distribution, contacting, off-gas, and ozone destructor inlet piping be purged before opening the various systems or subsystems. When entering the ozone contactor, personnel must recognize the potential for oxygen deficiencies or trapped ozone gas in spite of best efforts to purge the system. The operator should be aware of all emergency operating procedures required if a problem occurs. All safety equipment should be available for operators to use in case of an emergency.

Key O&M parameters include:

- Clean feed gas with a dew point of -60°C (-76°F), or lower, must be delivered to the ozone generator. If the supply gas is moist, the reaction of the ozone and the moisture will yield a very corrosive condensate on the inside of the ozonator. The output of the generator could be lowered by the formation of nitrogen oxides (such as nitric acid).

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- Maintain the required flow of generator coolant (air, water, or other liquid).
- Lubricate the compressor or blower in accordance with the manufacturer's specifications. Ensure that all compressor sealing gaskets are in good condition.
- Operate the ozone generator within its design parameters. Regularly inspect and clean the ozonator, air supply, and dielectric assemblies, and monitor the temperature of the ozone generator.
- Monitor the ozone gas feed and distribution system to ensure that the necessary volume comes into sufficient contact with the wastewater.
- Maintain ambient levels of ozone below the limits of applicable safety regulations.

Cost

The cost of ozone disinfection systems is dependent on the manufacturer, the site, the capacity of the plant, and the characteristics of the wastewater to be disinfected. Normally, costs for wastewater ozonation are based on at least a secondary level of treatment (i.e., average BOD and SS of 30 mg/L or less). Ozonation costs may not be competitive with other disinfection techniques under certain conditions, although equipment prices have been trending lower in recent years.

Figure 2 shows some typical cost estimates for ozone disinfection systems at various design flows in 1991. Costs are influenced by many factors that are process- and site-specific. The curves shown in Figure 2 are suitable for order-of-magnitude estimates only but should be sufficient to give a good indication of capital and annual O&M costs.

Because the concentration of ozone generated from either air or oxygen is so low, the transfer efficiency to the liquid phase is a critical economic consideration. For this reason, the contact chambers used are usually very deep and covered.

The annual operating costs for ozone disinfection include power consumption, chemicals and supplies, miscellaneous equipment repairs, and staffing requirements.

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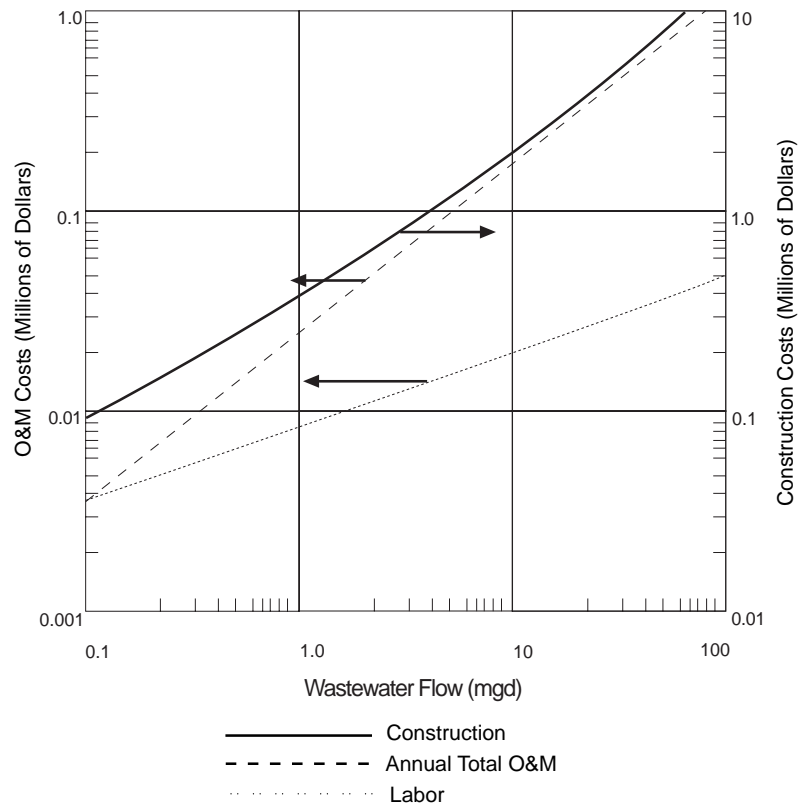


Figure 2: Annual O&M and Construction Costs for Ozone Disinfection

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For more information on ozone disinfection or a list of other fact sheets, contact the NSFC at West Virginia University, P.O. Box 6064, Morgantown, WV 26506-6064. Phone: (800) 624-8301 or (304) 293-4191. Fax: (304) 293-3161. World Wide Web site: <http://www.nsfsc.wvu.edu>.

The NSFC provides free and low-cost informational services and products to help homeowners and small communities address their wastewater needs. Also, information about manufacturers, consultants, regulations, and facilities can be obtained from the NSFC's databases.